APPENDIX A
Additional Information on GPS

A-1. Components of GPS. The GPS system consists of three major
segments: the space segment, the control segment and the user
segment.

    a.   Space Segment. The Space Segment consists of a nominal
constellation of 24 operational satellites (including 3 spares)
which have been placed in 6 orbital planes 10,900 miles (20,200
km) above the Earth's surface. The satellites are in circular
orbits with a 12-hour orbital period and inclination angle of 55
degrees. This orientation nearly ensures a minimum of five
satellites in view at any given time, anywhere on Earth. Each
satellite continuously broadcasts two low-power spread-spectrum
RE Link signals (L1 and L2). The L1 signal is centered at
1575.42 MHZ and the L2 signal is centered at 1227.6 MHZ.

    b.   Control Segment. The Control Segment consists of a
Master Control Station (in Colorado Springs), and a number of
monitor stations at various locations around the world. Each
monitor station tracks all the GPS satellites in view and passes
the signal measurement data back to the Master Control Station,
where the computations are performed to determine precise
satellite ephemeris and satellite clock errors. This data is
then up linked to the individual satellites, and subsequently
rebroadcast by the satellite as part of its navigation data
message.

    c.   User Segment. The User Segment is the collection of all
GPS receivers and their application support equipment such as
antennas and processors. This equipment allows users to receive,
decode, and process the information necessary to obtain accurate
position, velocity, and timing measurements. This data is used by
the receiver's support equipment for specific application
requirements.

A-2. Characteristics of GPS Signals. The satellites transmit
their signals using spread spectrum techniques employing two
different spreading functions: a 1.023 MHZ coarse/acquisition
(C/A) code on L1 only and a 10.23 MHZ precision (P) code on both
L1 and L2. The two spreading techniques provide two levels of
GPS service: Precise Positioning Service (PPS) and Standard
Positioning Service (SPS). SPS uses C/A code to derive position,
while PPS uses the more precise P(Y)-code.

(1) The P-code has a number of advantages over C/A code. First, the chipping rate of the P-code is 10 times faster, therefore the wavelength is 1/10th as long, giving the P-code a much higher resolution. Second, the higher chipping rate spreads the signal over a wider frequency range that makes the P-code much more difficult to jam. Third, by encrypting the P-code (creating the Y-code), the receiver is not susceptible to spoofing, or false GPS signals intended to deceive the receiver.

(2) The drawback of P-code is that it is relatively difficult to acquire because of its length and high speed. For this reason, many PPS receivers first acquire C/A code, then switch over to the P(Y)-code.

(3) Y code is an encrypted version of P code, used for anti-spoofing (A-S). Due to the similarity of these two codes, they are referred to collectively as P(Y)-code.

(4) Superimposed on both the P-code and the C/A code is a navigation message (NAV-msg) containing satellite ephemeris data, atmospheric propagation correction data, satellite clock-bias information, and almanac information for all satellites in the constellation.

(5) The GPS satellites use Bi-Phase Shift Keyed (BPSK) modulation to transmit the C/A and P(Y)-codes. The BPSK technique involves reversal of the carrier phase whenever the C/A or P(Y)-code transitions from 0 to 1 or from 1 to 0.

(6) To the casual observer, the very long sequence of ones and zeros that make up the C/A and P-codes would appear to occur in a random fashion and blend into the background noise. For this reason, they are known as pseudo-random noise (PRN). In actuality, the C/A and P-codes generated are precisely predictable to the start time of the code sequence and can be duplicated by the GPS receiver. The amount the receiver must offset its code generator to match the incoming code from the satellite is directly proportional to the range between the GPS receiver antenna and the satellite.

(7) By the time the spread spectrum signal arrives at the GPS receiver, its signal power is well below the thermal noise level. To recover the signal, the receiver uses a correlation method to compare the incoming signals with its own generated C/A or P(Y) codes. The receiver shifts its generated code until the two codes are correlated.

A-3. <u>Determining Positions</u>.

a. The receiver continuously determines its geographic position by measuring the ranges (the distance between a satellite with known coordinates in space and the receiver*s antenna) of several satellites and computes the geometric intersection of these ranges.

b. To determine a range, the receiver measures the time required for the GPS signal to travel from the satellite to the receiver antenna. The resulting time shift is multiplied by the speed of light, arriving at the range measurement.

c. Since the resulting range measurement contains propagation delays due to atmospheric effects, as well as satellite and receiver clock errors, it is referred to as a "pseudorange." A minimum of four pseudorange measurements is required by the receiver to mathematically determine time and the three components of position (latitude, longitude, and elevation). The solution of these equations may be visualized as the geometric intersection of four ranges from four known satellite locations.

d. If one of the variables is known, such as elevation, only three satellite pseudorange measurements are required for a PVT solution, and only three satellites would need to be tracked.

A-4. <u>GPS Error Budgets and Accuracies</u>.

a. GPS accuracy has a statistical distribution that is dependent on a number of important factors, including: dilution of precision (DOP) satellite position and clock errors, atmospheric delay of satellite signals, selective availability, signal obstruction, and multipath errors.

b. Each satellite follows a known orbit around the earth and contains a precise atomic clock. The monitor stations closely track each satellite to detect any errors in its orbits or clock. Corrections for errors are sent to each satellite as ephemeris and almanac data. The ephemeris data contains specific position and clock correction data for each satellite while the almanac contains satellite position data for all satellites. The NAV set receives the ephemeris and almanac data from the satellites and uses this data to compensate for the position and clock errors when calculating the NAV data.

c. There are two ways to compensate for the atmospheric delays: modeling and direct measurement. The ionospheric and tropospheric delays are inversely proportional to the square of the frequency. If a receiver can receive L1 and L2 frequencies, it can measure the difference between the two signals and calculate the exact atmospheric delay.

d. Currently, most receivers use mathematical models to approximate the atmospheric delay. The tropospheric effects are fairly static and predictable and a model has been developed that effectively removes 92-95 percent of the error.

e. The ionosphere is more difficult to model due to its unusual shape and the number of factors that affect it. Therefore, a model has been developed that requires eight variable coefficients. Every day, the Control Segment calculates the coefficients for the ionospheric model and uplinks them to the satellites. The data is then rebroadcast in the NAV messages of the C/A- and P(Y)-codes. This model can effectively remove 55 percent of the ionospheric delay.

f. Multipath errors result from the combination of data from more than one propagation path. This distorts the signal characteristics from which the range measurements are made, resulting in pseudorange errors. These errors are dependent on the nature and location of a reflective surface peculiar to each user location. The effects are less detrimental for a moving user since small antenna movement can completely change the multipath characteristics.

g. The receiver is designed to reject multipath signals. First, the active patch antennas are designed to have a sharp gain roll-off near the horizon while providing nominal gain for the primary satellite signal. Since most multipath signals are reflected from ground structures, they tend to be attenuated. Second, the antenna is right-hand polarized. When a right-hand polarized GPS signal is reflected off a conductive surface, it becomes left-hand polarized, and rejected by the antenna. The receiver also has hardware and software designed to reduce the effects of any multipath interference errors.

A-5. GPS Positioning Services. GPS satellites provide two levels of navigation service: Standard Position Service (SPS) and Precise Position Service (PPS).

(1) SPS receivers use GPS information broadcast in the clear and is available to anyone in the world. This information contains built-in errors that limit the accuracy of the receiver. This is a security technique called Selective Availability (SA). These SA errors are variable. In normal conditions, the U.S. government guarantees that these errors do not exceed 100 meters horizontal, 140 meters vertical, and time accuracy of 340 nanoseconds 95 percent of the time. Thus, there are times when an SPS receiver error exceeds these limits. SA is always on. SPS receivers are for civil use and a PLGR without crypto keys will act like an SPS receiver.

(2) PPS receivers use the same information as SPS receivers. They also read encoded information that contains the corrections to remove the intentional SA errors. Only users who have crypto keys to decode this information get the PPS accuracy. U.S. government agencies and some Allies are authorized to have these crypto keys. A PLGR with valid crypto keys loaded and verified is a PPS receiver.

(3) To protect authorized users from hostile attempts to imitate the GPS signals, a security technique called Anti-spoofing (A-S) is also used. This is an encrypted signal from the satellites that can only be read by PPS receivers. A receiver with valid crypto keys loaded and verified, reads this encrypted signal and operates in a spoofing environment.

(4) Normal operation of the GPS receiver requires undisturbed reception of signals from as few as four satellites (in normal 3-D mode) or three satellites in fixed-elevation mode. The signals propagating from the satellites cannot penetrate water, soil, walls, or other similar obstacles. The antenna and the satellites are required to be in a "line-of-sight" with each other. Therefore, GPS cannot be used for underground positioning in tunnels, mines, or subsurface marine navigation. In surface navigation, the signal can be obscured by buildings, bridges, and other matter that might block an antenna*s line-of-sight from the GPS satellites in view. In airborne applications, the signal can be shaded by the aircraft*s body during high banking angles.

A-6. Differential GPS (DGPS). Differential GPS (DGPS) may be used to eliminate the effects of SA and correct certain bias-like errors in the GPS signals. A Reference Station receiver measures ranges from all visible satellites to its surveyed position. Differences between the measured and known ranges are computed and applied to differential equipped receivers in a local area.

These differences (or Pseudo-Range Corrections) can be
transmitted by radio and applied in real-time, or can be
downloaded into computer software and applied during
postprocessing.